LEVEL II

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ENVIRONMENTAL TEST AND EVALUATION OF A MOLECULAR SIEVE ON-BOARD OXYGEN GENERATION SYSTEM

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Because of the high support costs, increase in aircraft down time, and hazards associated with the use of liquid oxygen, development has been progressing on On-Board Oxygen Generation Systems which have the capability of meeting the requirements of a two man open loop breathing schedule. An evaluation program was conducted on an oxygen generator utilizing the molecular sieve concept of nitrogen absorption. The system was developed to establish unit performance in the environment anticipated during in flight operation. Oxygen concentration has been evaluated as a function of inlet air pressure, oxygen

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20. outlet flowrate, altitude, inlet air and ambient temperatures, and rates of climb and descent. The system has successfully demonstrated the ability, under certain conditions, to provide a breathing gas composed of 95 percent oxygen. It will also provide adequate amounts of breathing gas and sufficient oxygen concentrations for a two man open loop breathing schedule to an altitude of 32,000 feet with modification of the oxygen regulator to operate at lower inlet pressures and mixtures of less than 100 percent oxygen. Above this altitude, a pressure breathing schedule, which accounts for less than 100 percent oxygen gas mixture, would be required.

SUMMARY

Because of the high support costs, increase in aircraft down time, and hazards associated with the utilization to liquid oxygen, development has been progressing on On-Board Oxygen Generation Systems which have the capability of meeting the requirements of a two-man open loop breathing schedule. One system, which utilizes a molecular sieve concept for oxygen generation, has been subjected to environmental test and evaluation at the Naval Air Development Center. The evaluation program was conducted to verify that design criteria have been met and establish unit performance in the environment anticipated during flight testing. In addition to vibration and acceleration testing, oxygen concentration has been evaluated as a function of inlet pressure, outlet flowrate, altitude, inlet air, and ambient temperatures, and rates of climb and descent. The system has successfully demonstrated the ability under certain conditions, to provide a breathing gas composed of 95 percent oxygen and 5 percent argon. It will also provide adequate amounts of breathing gas and sufficient oxygen concentrations for a two-man open loop breathing schedule to an altitude of 32,000 feet without pressure breathing. It is recommended that further development of the concept continue, with consideration given to the impact of thermal conditions and inlet pressure requirements on the performance of the system.

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INTRODUCTION

Development has been progressing on On-Board Oxygen Generation Systems which have the capability of meeting the requirements of a two-man open loop breathing schedule. The utilization of such a system will result in safer operating conditions due to the removal of hazardous stores of liquid oxygen, improved efficiency with increased aircraft flight time, and substantial savings resulting from the elimination of support equipment and manpower required by liquid oxygen systems. Development of a 100 percent OBOG system has, however, imposed severe penalties on aircraft resources and interface requirements.

An alternative system, which utilizes the molecular sieve concept of oxygen generation, has been developed under the sponsorship of Naval Air Systems Command (AIR-340B and AIR-531). The system selectively adsorbs nitrogen from a process airstream, leaving an effluent gas enriched in oxygen. This concept has demonstrated the ability to provide a breathing gas composed of 95 percent oxygen and 5 percent argon, an inert gas. The utilization of such a system significantly reduces the requirements of aircraft resources and interface.

The purpose of this report is to detail the results of tests conducted on the Molecular Sieve Oxygen Generator. The tests, performed at the Environmental Test Facilities of the Naval Air Development Center, and at the Vibration Laboratories of the Bendix Corporation, were made to evaluate unit performance when subjected to conditions anticipated during in-flight operation. This unit will be flight tested on the Navy EA-6B "Prowler," in addition to systems under further development to be used on board the AV-8A "Harrier."

Oxygen concentration of the system output was of prime concern, and was determined as a function of inlet pressure, outlet pressure, outlet flow, altitude (exhaust pressure), ambient and inlet temperatures, and rates of altitude climb and descent.

DESCRIPTION OF EQUIPMENT TESTED

The Molecular Sieve Oxygen Generator (figures 1, 2, and 3) used in this test program was produced by the Bendix Corporation, Instruments and Life Support Division, Davenport, Iowa, under Navy contract N62269-75-C-0270. The system has dimensions of 12 inches (30.5 cm) wide by 13 inches (33 cm) high by 15 inches (38.1 cm) long, and weighs approximately 55 pounds (25 kg). An overall size comparison of the unit with standard 5 and 10 liter liquid oxygen converters is shown in figure 4.

System operation requires a pressurized airstream (25 to 60 psig) as a source of oxygen, and a power supply of 28 VDC for operation of a rotating control valve. The MSOG draws 200 milliamps under normal operations, consuming 5.6 watts of power.

A schematic of the molecular sieve unit is presented in figure 5. The system operates on a pressure swing process, alternately processing two beds of type 5A molecular sieve material to provide a continuous flow of oxygen.

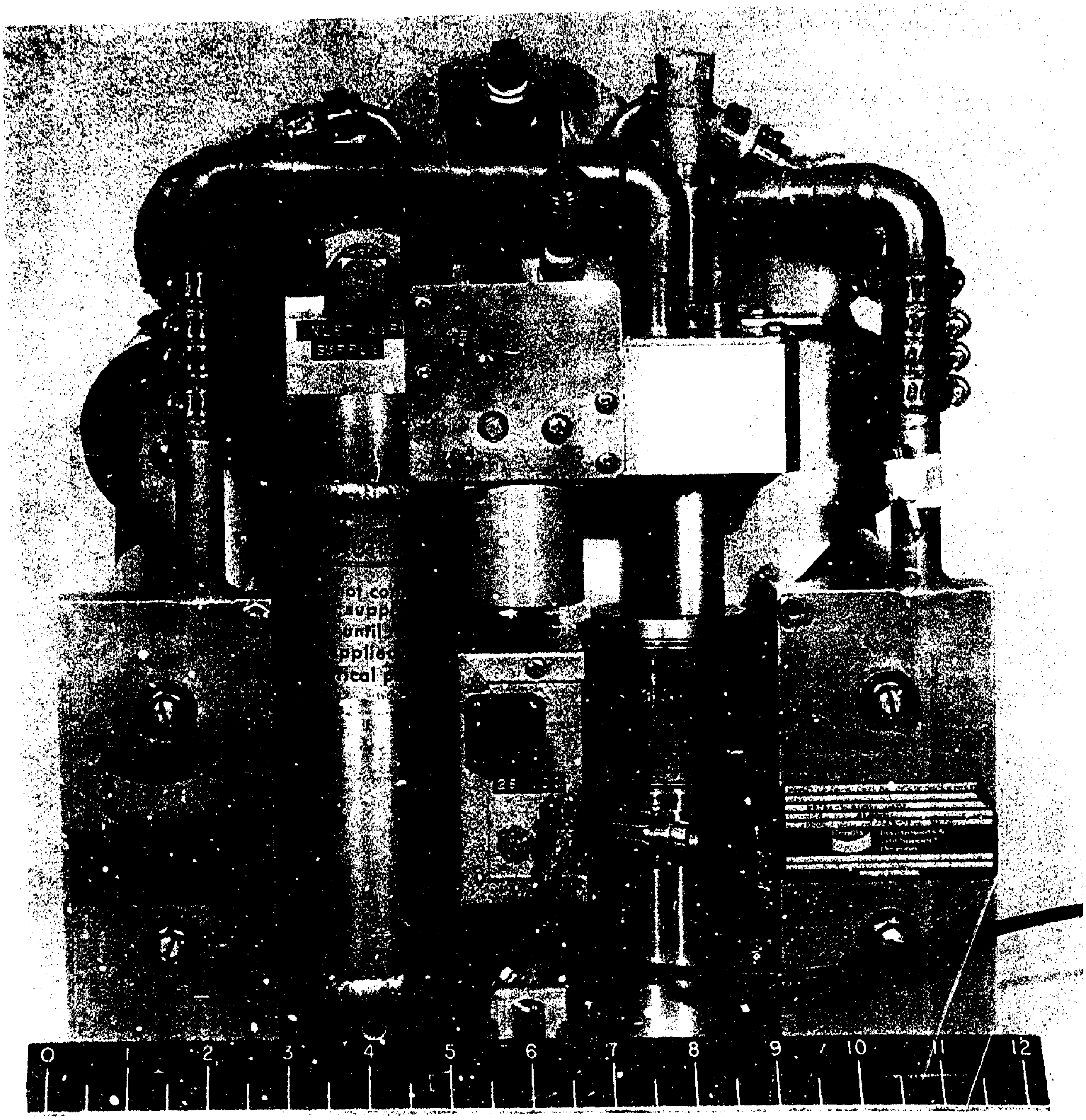

FIGURE 1 Molecular Sieve Oxygen Generator (MSOG) (Front View)

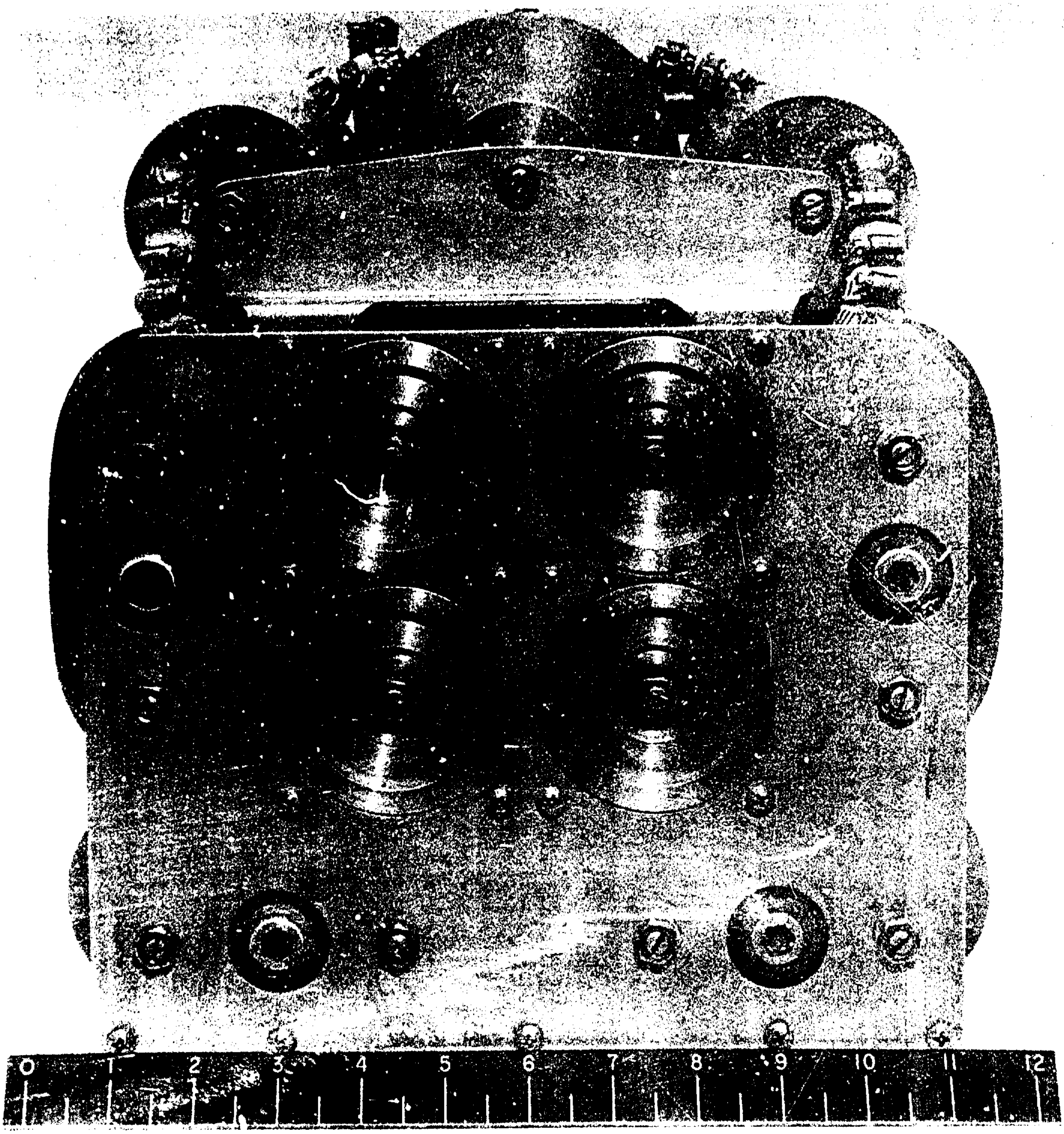

FIGURE 2 - MSOG (Rear View)

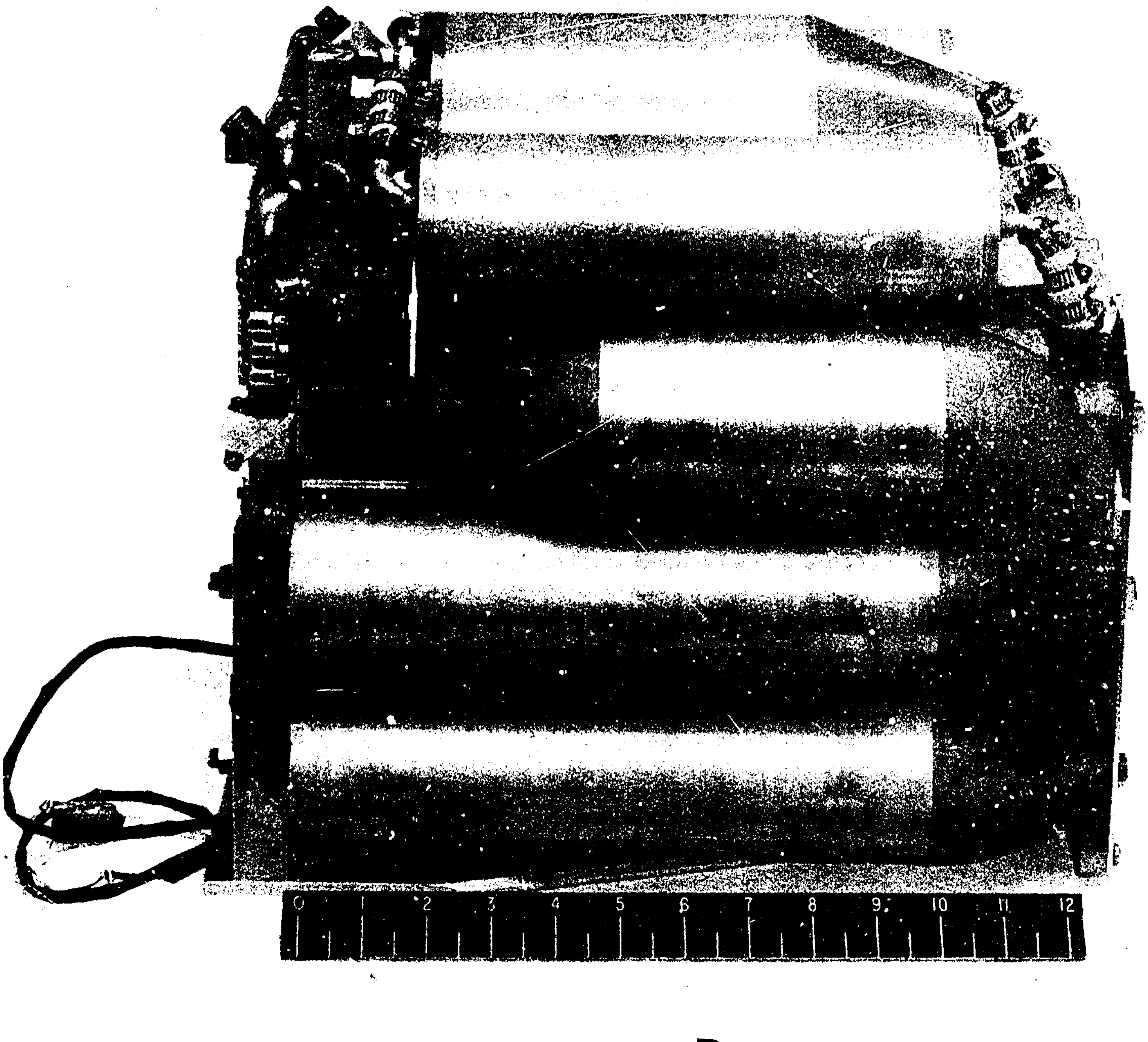

FIGURE 3 - MSOG (Side View)

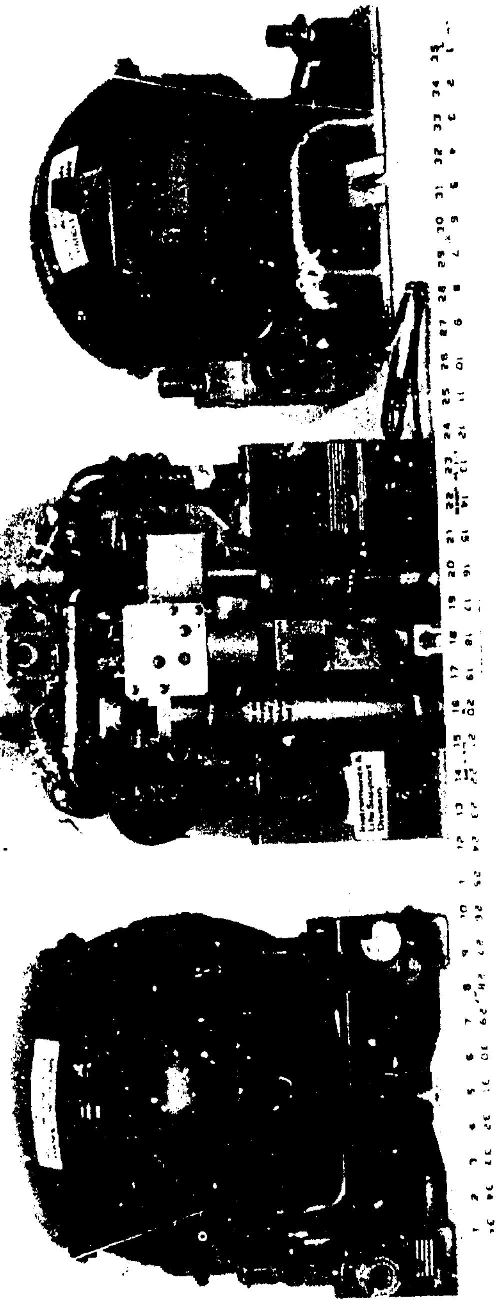

FIGURE 4 - Comparison of the MSOG and 5 and 10 Liter Liquid Oxygen Converters

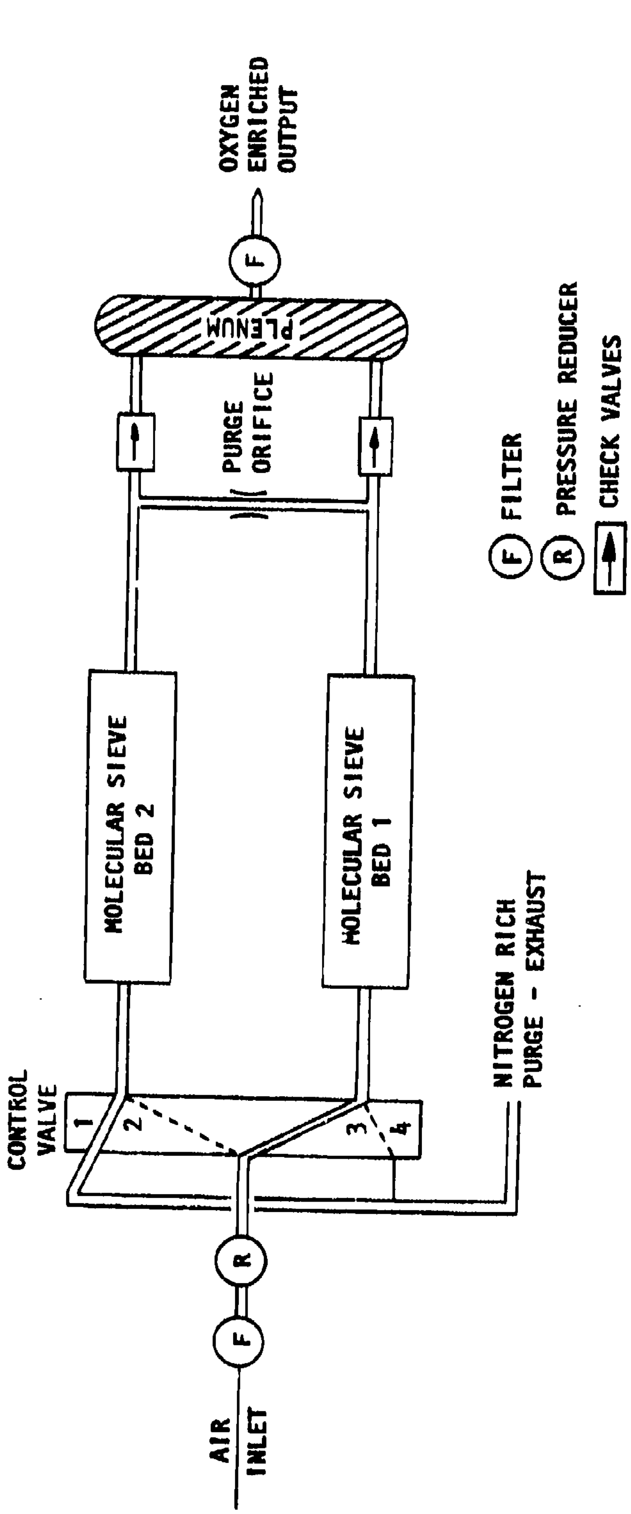

FIGURE 5 - MSOG Schematic

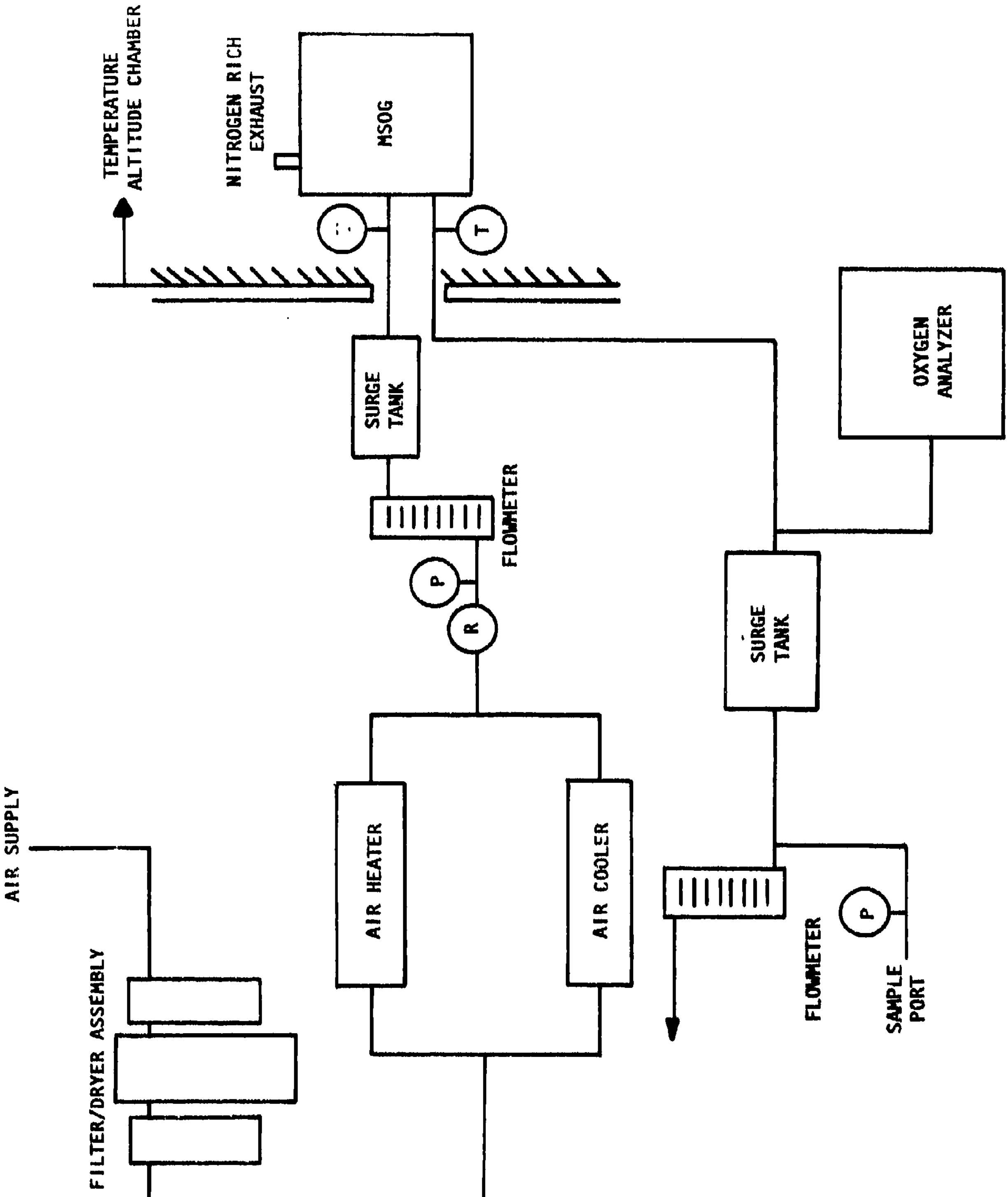

FIGURE 6 - MSOG Test Equipment Schematic

Engine bleed air is admitted to the beds through a filter, pressure reducer, and rotating control valve. As air passes through the beds, the smaller nitrogen molecules are selectively adsorbed by the molecular sieve pellets, leaving an oxygen enriched breathing gas. This passes through a check valve to a plenum (approximately one liter volume) before leaving the unit for breathing by the crew members. At the same time, a portion of this gas enters the second bed through a purge orifice for desorption of nitrogen, which exits through an exhaust port. With rotation of the control valve, the roles of the beds are then reversed. Total cycle time, that is, for complete adsorption and desorption of both beds, is approximately 17 seconds, with a constant valve rotation of 3.5 rpm.

TEST EQUIPMENT

The test apparatus is shown schematically in figure 6, and pictorially in figure 7. The MSOG was placed within the altitude/temperature chamber (figure 8) in order to evaluate unit performance with variation in altitude and ambient temperature.

House air (100 PSIG, 70 ± 5 degrees Fahrenheit) was first passed through a filter and dryer assembly for removal of oil and water droplets which may hinder bed absorption, then through either a heater or chiller for variation of inlet air temperature. A diaphram regulator was used to control inlet air pressure which, along with flowrate and temperature, was monitored continually during each test.

Enriched air outlet flow was controlled via a gate valve after entering a surge tank (2100 cu. in. volume) for flow stabilization. A sample of this gas was taken just upstream of this tank (400 cc/min.) and processed by an oxygen analyzer. These results, which showed a concentration of oxygen (±1 percent error), were also monitored continually during each test and recorded manually. Samples were also drawn at designated points throughout the test program and analyzed through use of a chromatograph for verification of results.

METHOD OF TEST

MIL-STD-810C, "Environmental Test Methods", was utilized to establish testing guidelines. Allowance was made for the prototype nature of the unit, particularly with respect to vibration and acceleration levels. Therefore, the evaluation program was not established to meet the requirements of full qualification.

Unit performance has been evaluated as a function of inlet air pressure, enriched air outlet flowrate, altitude (nitrogen exhaust pressure), inlet air temperature, amibient temperature, and rates of altitude climb and descent. For those runs involving climb and descent, the NATOPS manual for the EA-6B "Prowler" was consulted to set the times, in minutes, for ascending and descending rates. A summary of each test attempted in the program is presented in the Experimental Protocol (appendix A, section 3).

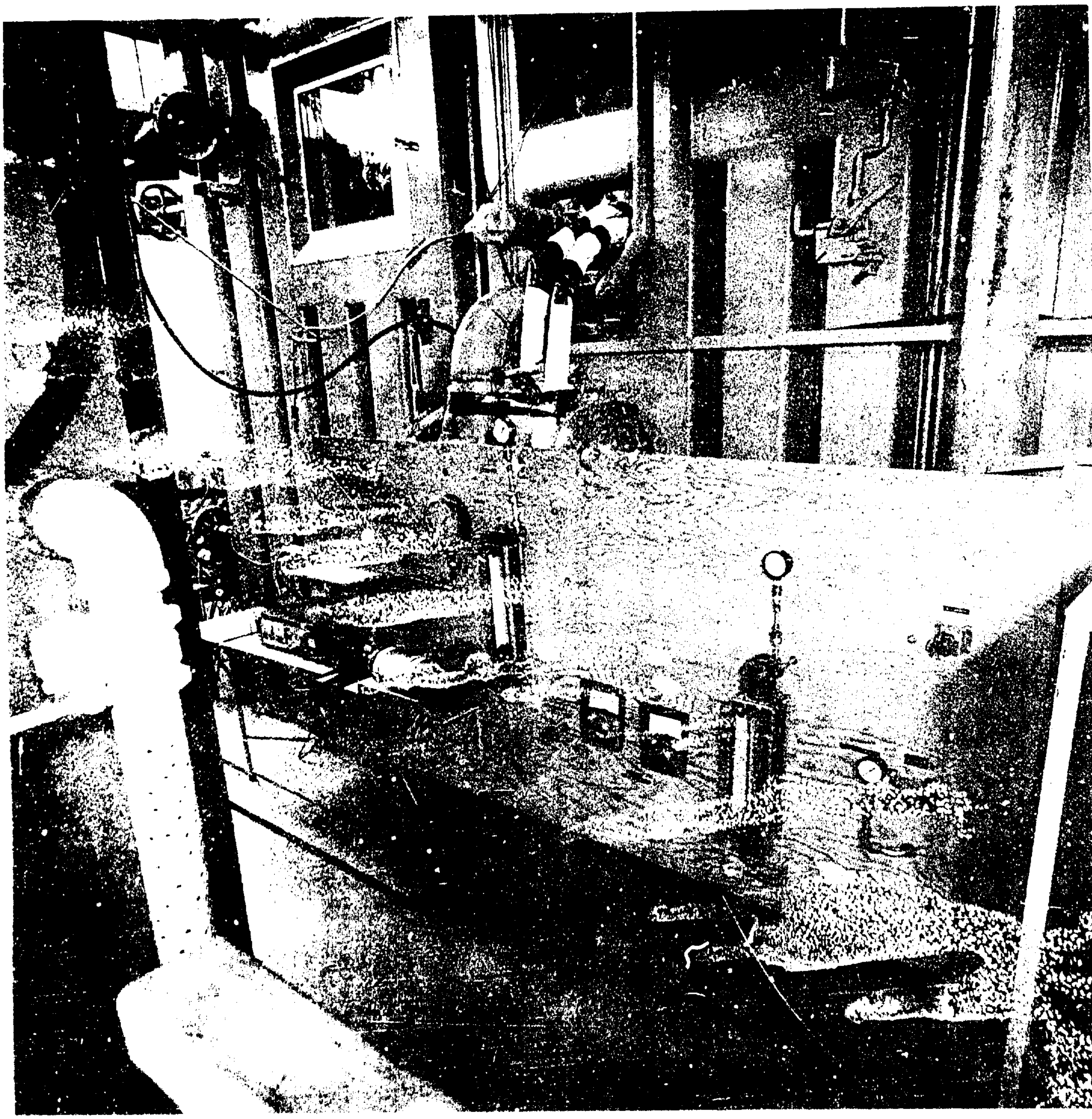

FIGURE [illegible] Test Equipment Set-Up (Chamber in Background)

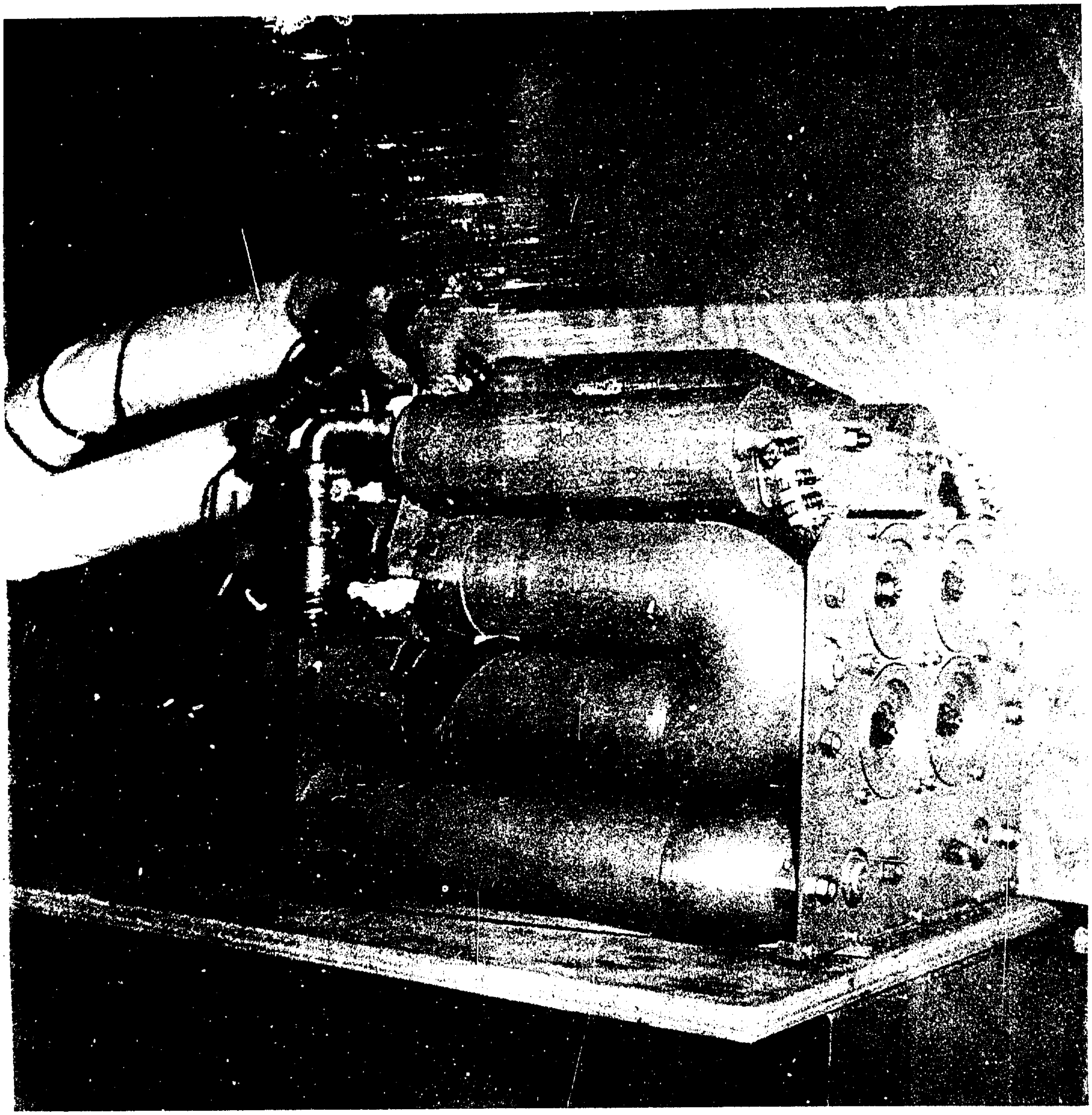

FIGURE 8 - M50G Placed Within the Temperature/Altitude Chamber

RESULTS AND DISCUSSION

Flow requirements for the MSOG were measured and are presented in figure 9. Inlet flow was found to be primarily a function of inlet pressure, increasing with pressure. To a lesser extent, inlet flow was also found to be a function of altitude, increasing with altitude at low pressure (below 25 PSIG), and decreasing at high pressure (above 40 PSIG), although the variations were slight. A maximum inlet flowrate (82 lbm/hr) was observed at sea level with an inlet pressure of 60 PSIG. Inlet pressures above 40 PSIG are subject to the operation of the MSOG internal pressure reducer, which established the decreasing slope of the curve. The pressure differential of the reducer is presented in table I (Bendix Data).

Figures 10 through 18 present oxygen concentration as a function of inlet pressure, outlet flowrate and altitude. Numerical data used in the construction of these plots is presented in appendix B. As seen from these results, oxygen concentration increased with inlet pressure and decreased with outlet flowrate. Unit performance (oxygen concentration) also increased with altitude to 40,000 feet. Results at 50,000 feet were found to be less favorable than those at 40,000 feet, with slight drops in oxygen concentration noted with flows of 13.1, 26.2, 39.3, and 52.4 lpm drawn. Whenever 13.1 lpm was drawn from the unit at 20,000 feet or above, the resulting concentration always fell within the range of 94 to 95 percent, which more than adequately meets the oxygen requirements of MIL-D-19326E (table II - reference 2).

Of particular interest were the results of points in the pressure/altitude matrix involving low inlet pressure and altitude. As altitude increased, the maximum flow which could be drawn from the unit decreased. Low value for outlet flow (10 lpm max.) was found with an inlet pressure of 8 PSIG and altitude of 40,000 feet. As mentioned previously, there exists a low volume of supply air at low input pressure. This, coupled with low pressure at the nitrogen exhaust at high altitude, leads to rapid bed evacuation and decreased volume of breathing gas available.

The second set of runs as listed in the experimental protocol deal with variation of inlet air temperature and its effect on unit performance. They were conducted at standard ambient conditions, with an inlet pressure of 40 PSIG and outlet flowrate of 13.1 lpm. Inlet air temperature was varied from 14 to 160 degrees Fahrenheit, with no appreciable effect on oxygen concentration noted. Results recorded all fell within the range of 94.4 to 94.6 percent oxygen.

Variation of chamber ambinet temperature yielded signigicant information as to the performance of the molecular sieve concentrator. To observe unit performance when exposed to a low ambient temperature, it was intended to conduct a two hour test at -65 degrees Fahrenheit and sea level. Inlet air temperature (66 ± degrees Fahrenheit), pressure (40 PSIG), and outlet flowrate (13.1 lpm) remained constant throughout the test. The results are shown in figure 19. The test was discontinued after 40 minutes due to the low oxygen concentrations recorded. At the conclusion of the test, chamber ambient read -65 degrees Fahrenheit and bed temperature (surface) read -57 degrees Fahrenheit, yielding an oxygen concentration of 33.3 percent.

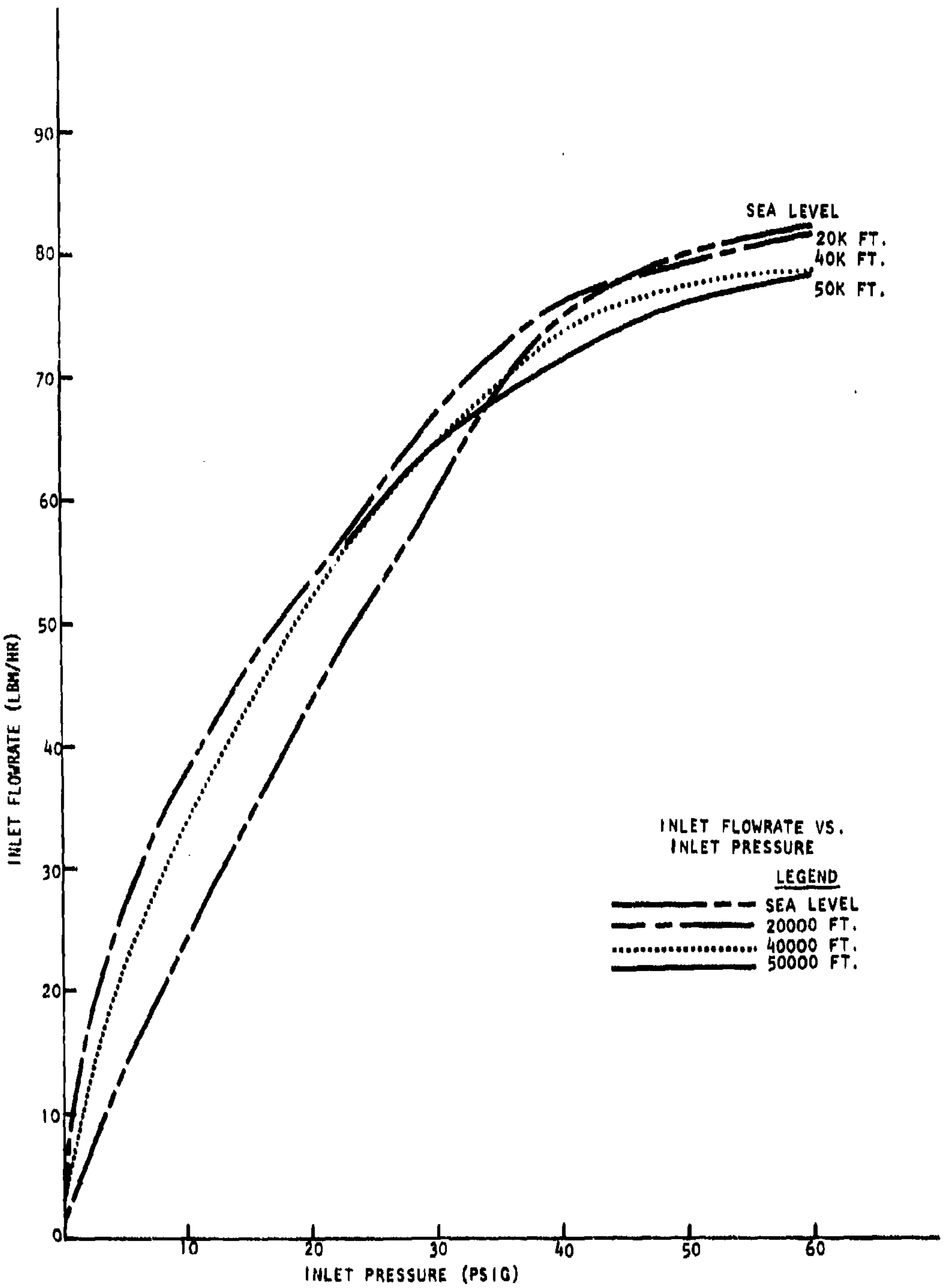

FIGURE 9 - Plot - Air Intake Versus Inlet Pressure

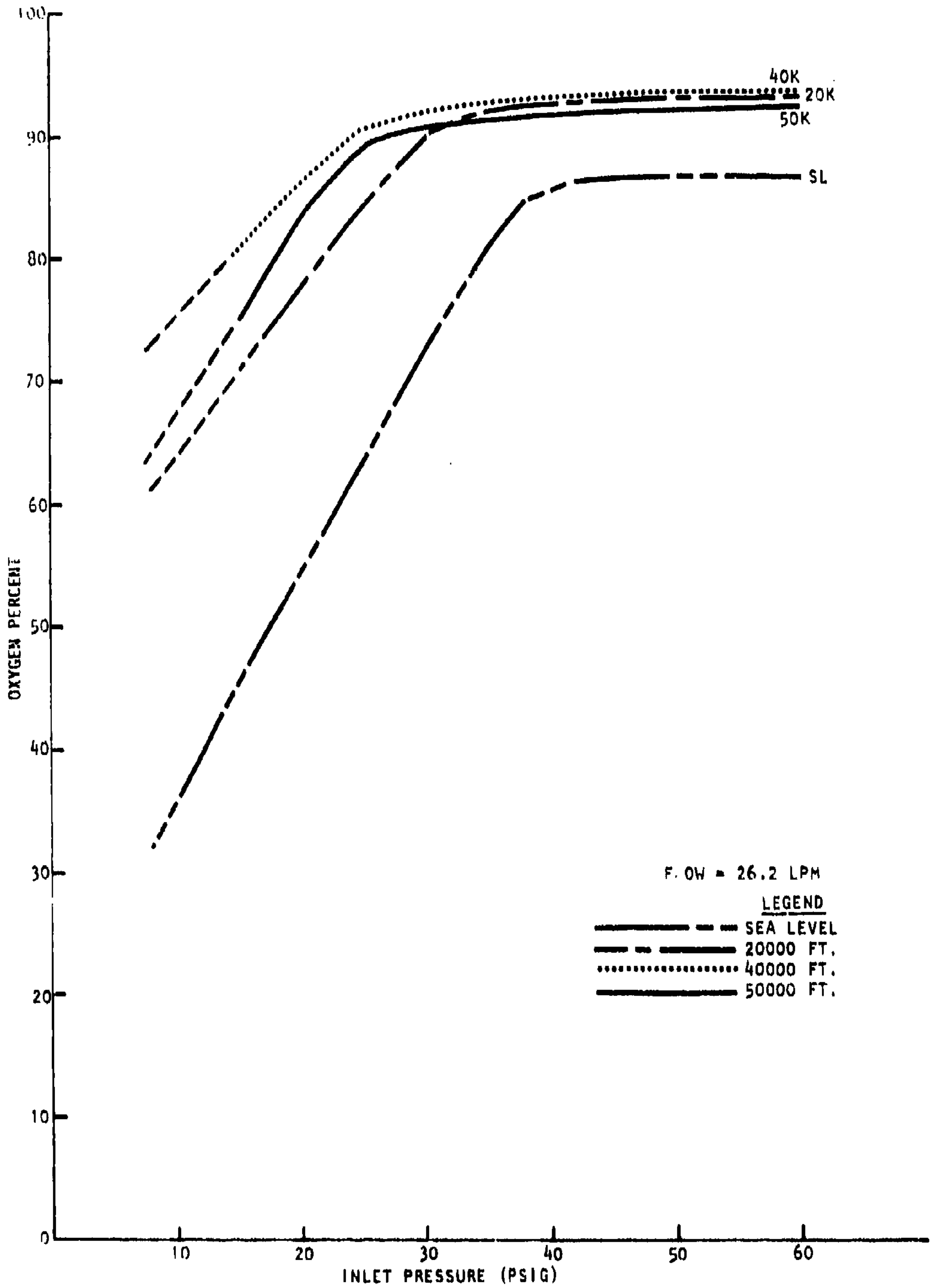

FIGURE 10 - Plot - Oxygen Concentration Versus Inlet Pressure (Flow = 26.2 LPM)

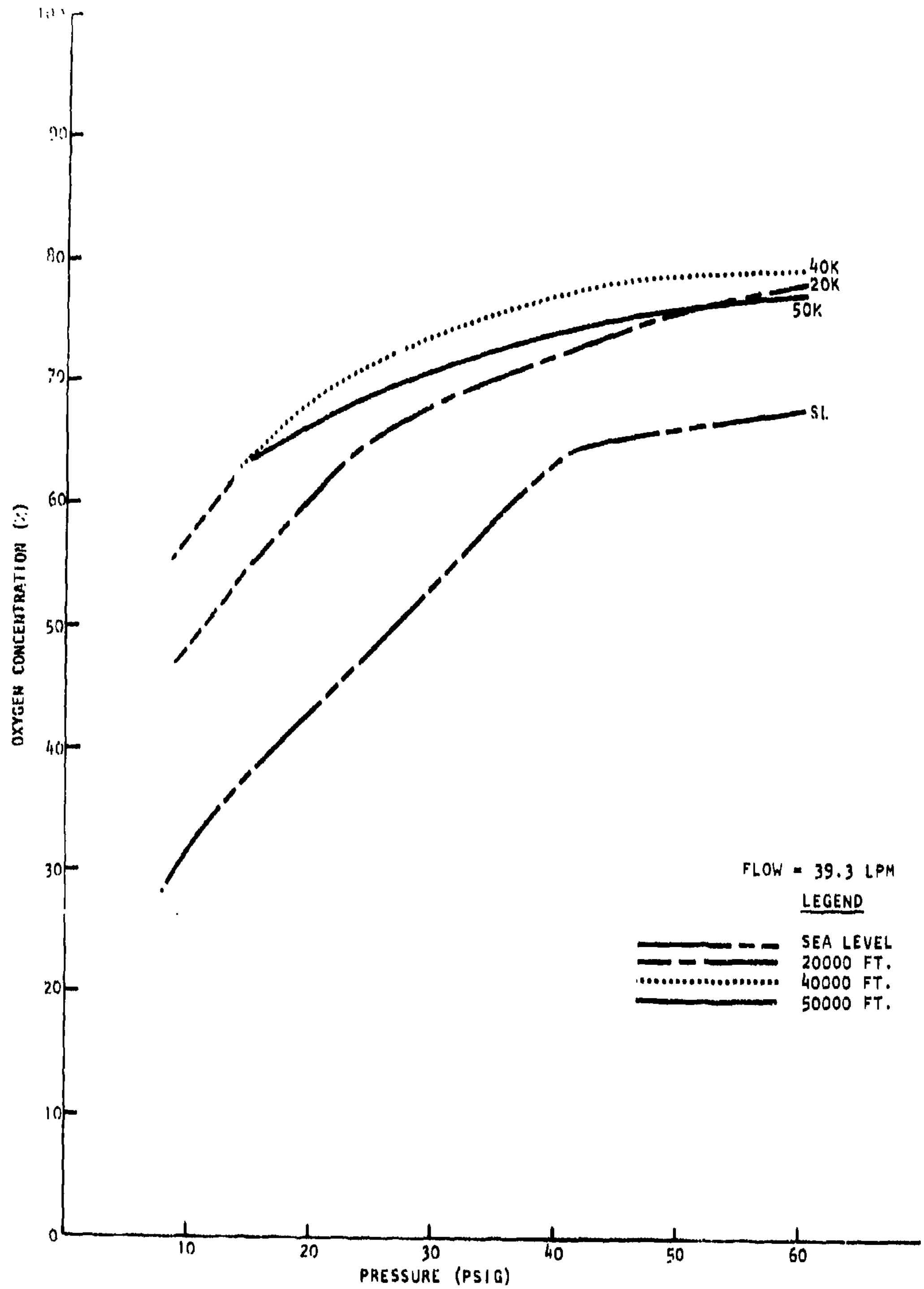

FIGURE 11 - Plot - Oxygen Concentration Versus Inlet Pressure (39.3 LPM)

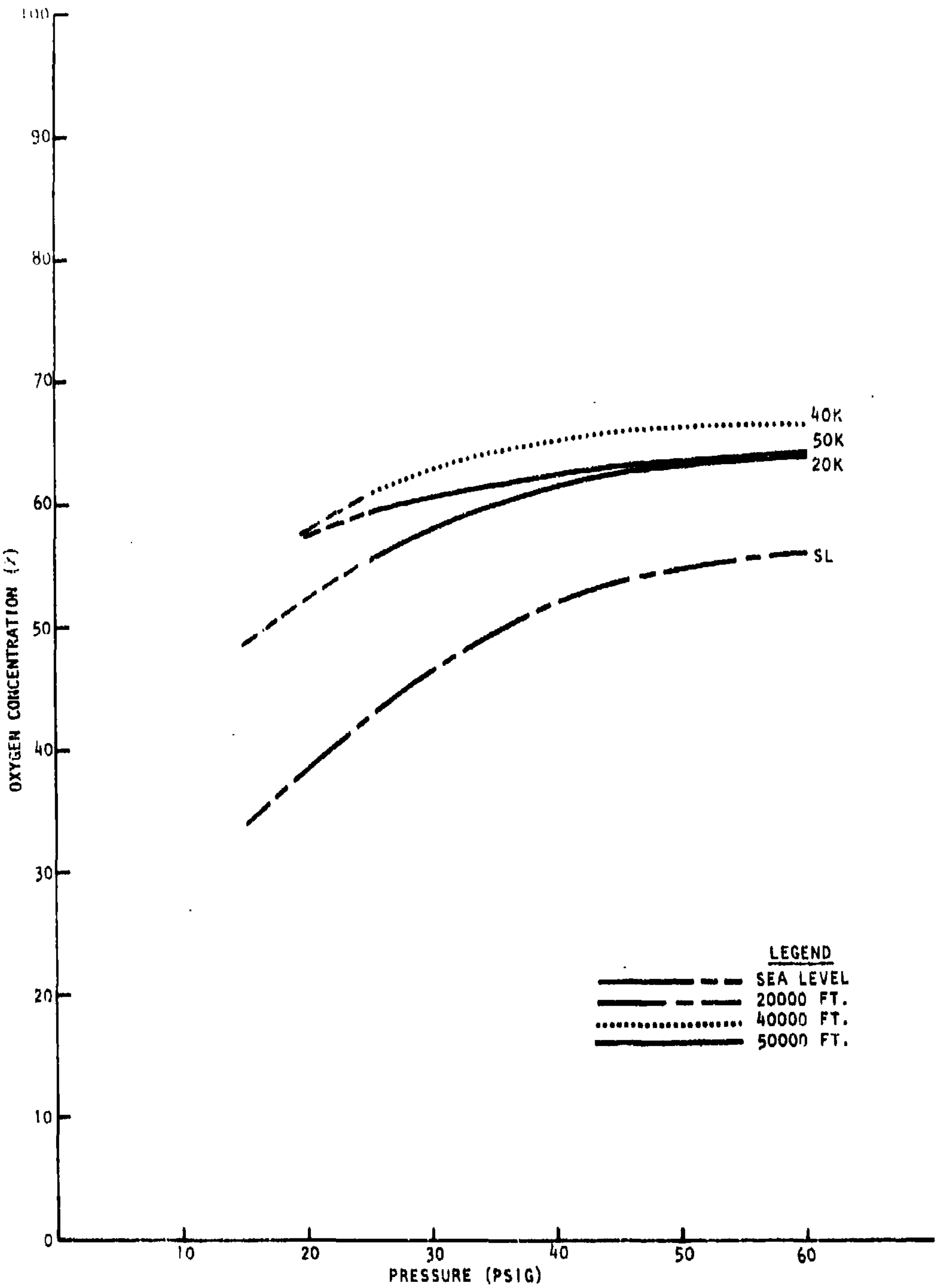

FIGURE 12 - Plot - Oxygen Concentration Versus Inlet Pressure (52.4 LPM)

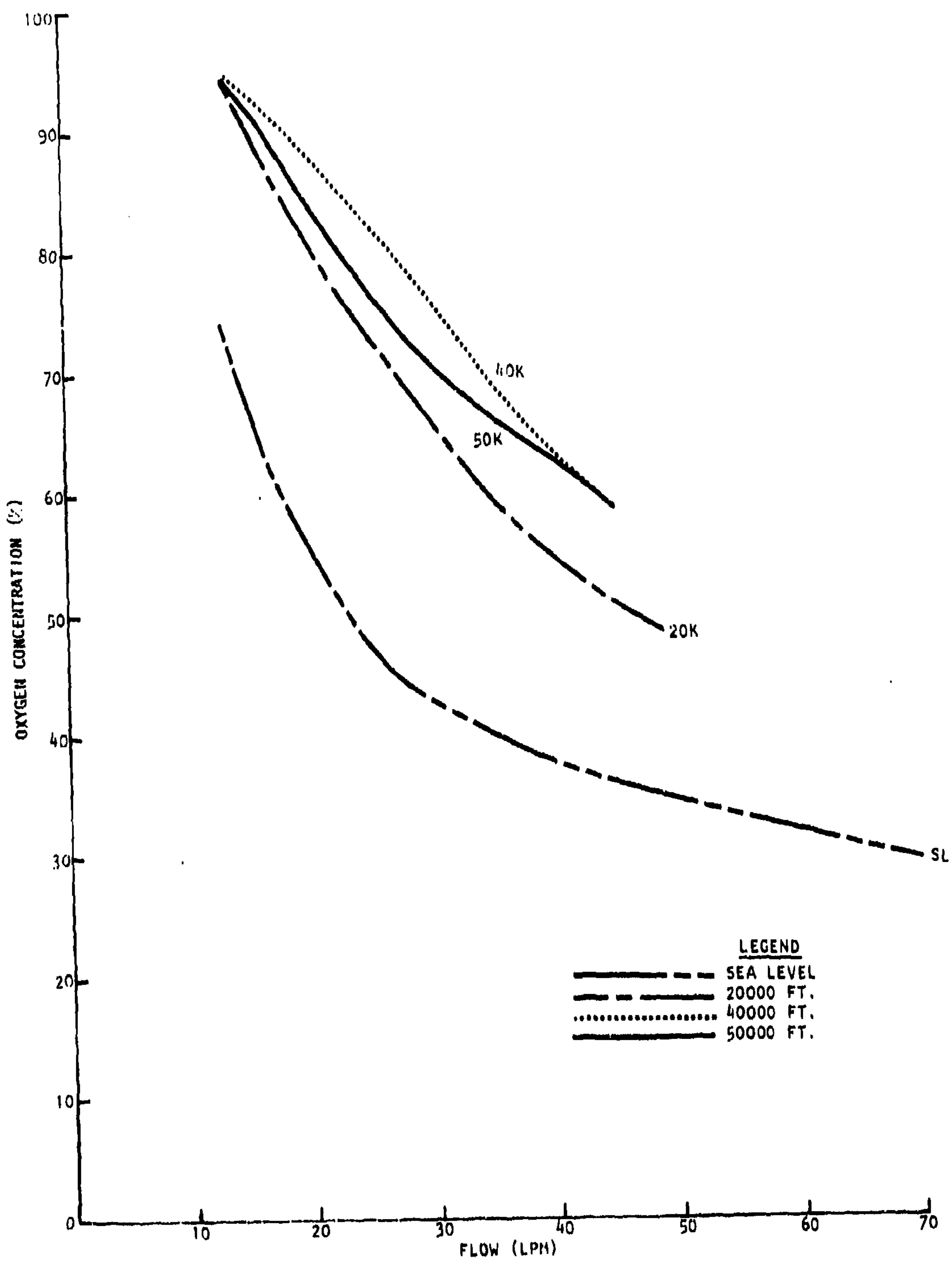

FIGURE 13 - Plot - Oxygen Concentration Versus Outlet Flowrate (15 PSIG Inlet)

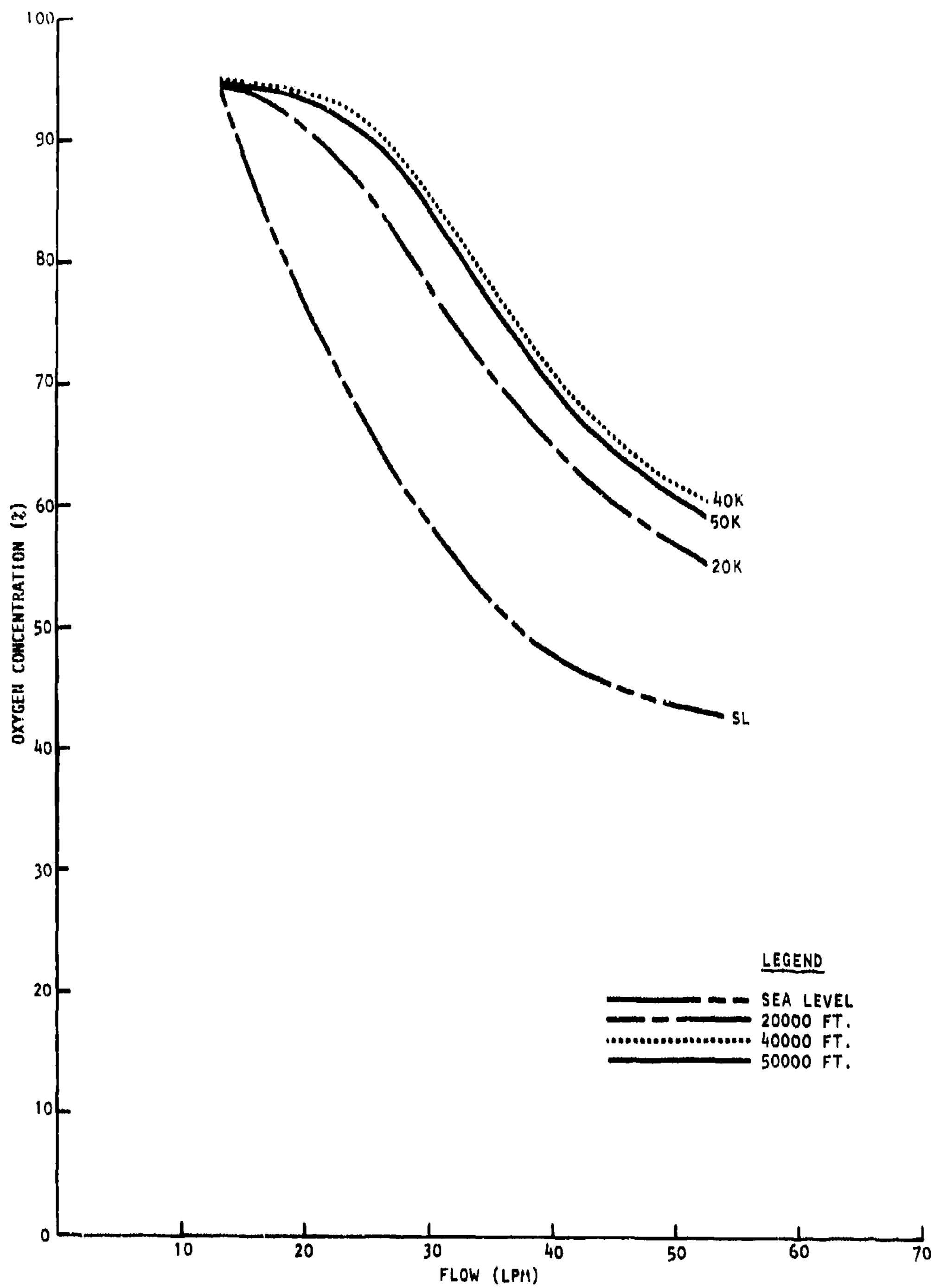

FIGURE 14 - Plot - Oxygen Concentration Versus Outlet Flowrate (25 PSIG)

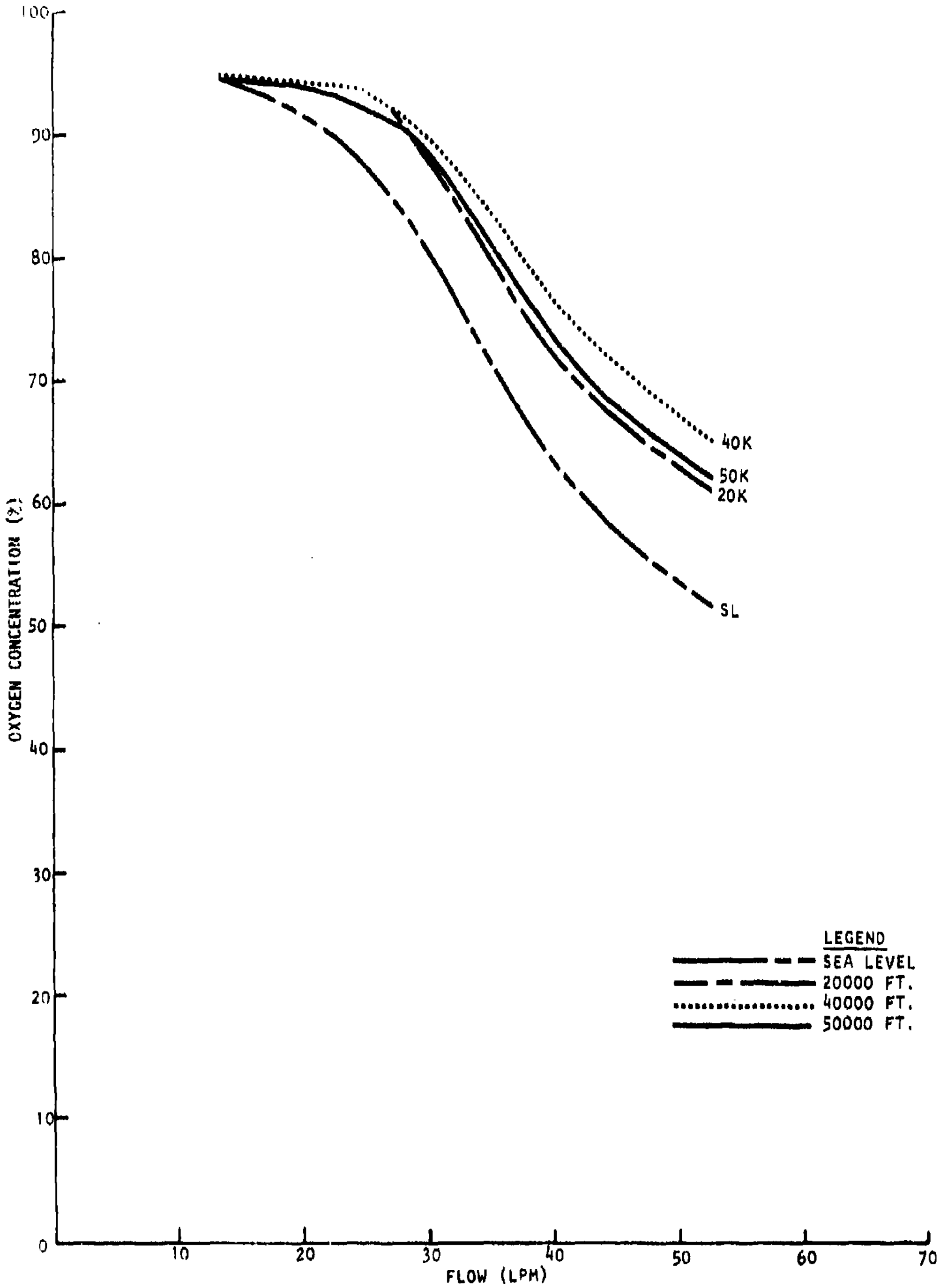

FIGURE 15 - Plot - Oxygen Concentration Versus Outlet Flowrate (40 PSIG)

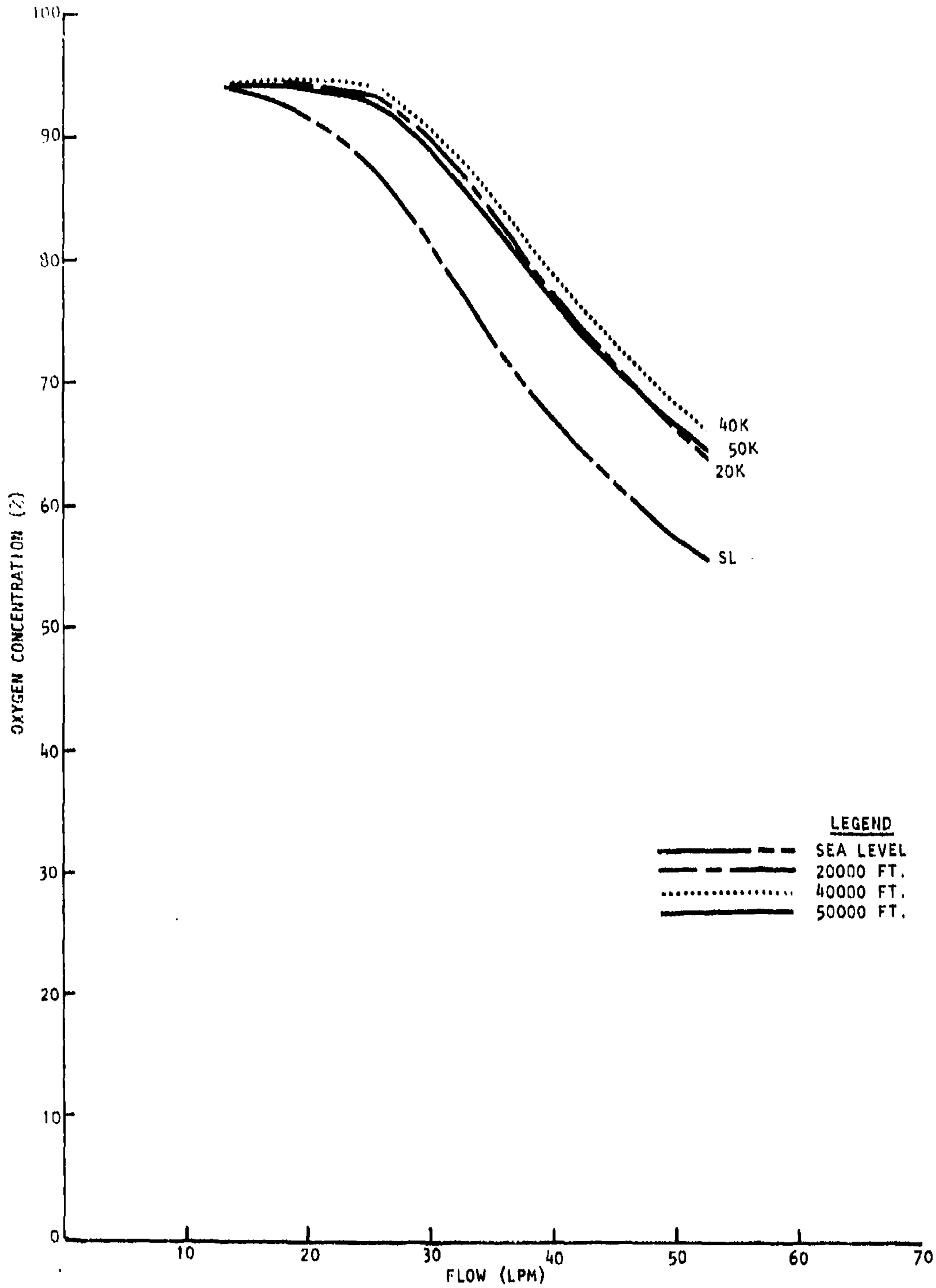

FIGURE 16 - Plot - Oxygen Concentration Versus Outlet Flowrate (60 PSIG)

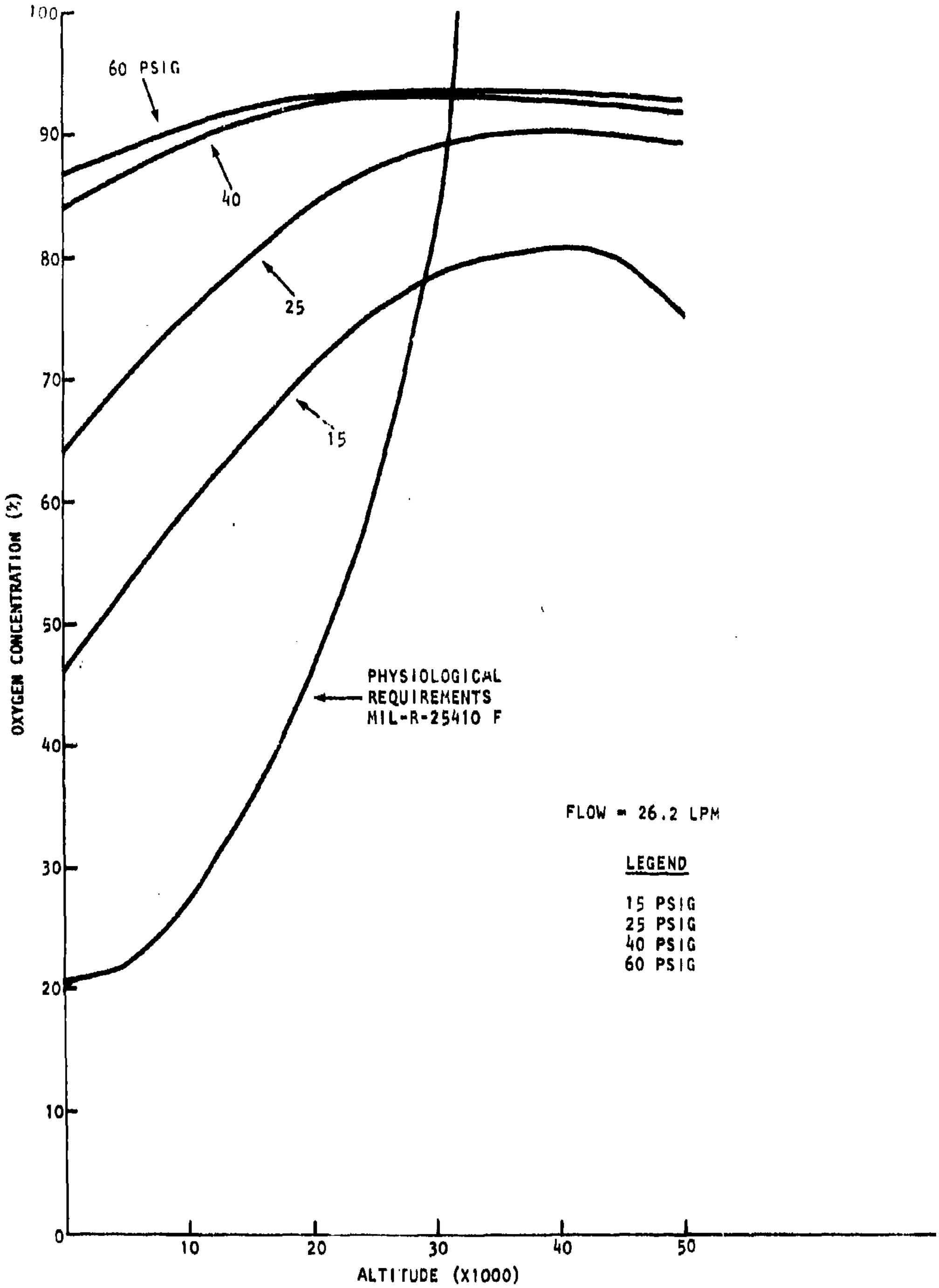

FIGURE 17 - Plot - Oxygen Concentration Versus Altitude (26.2 LPM)

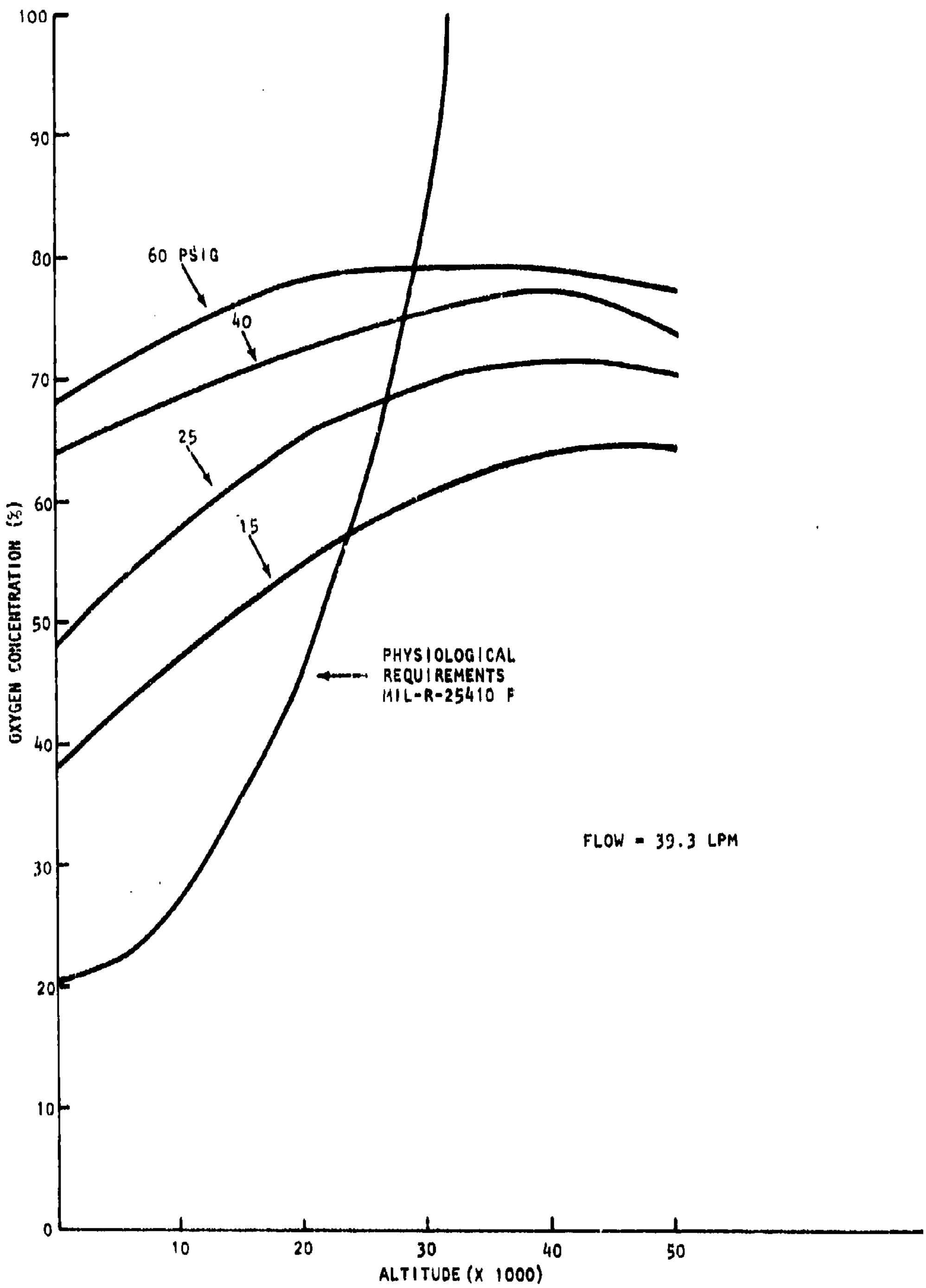

FIGURE 18 - Plot - Oxygen Concentration Versus Altitude (39.3 LPM)

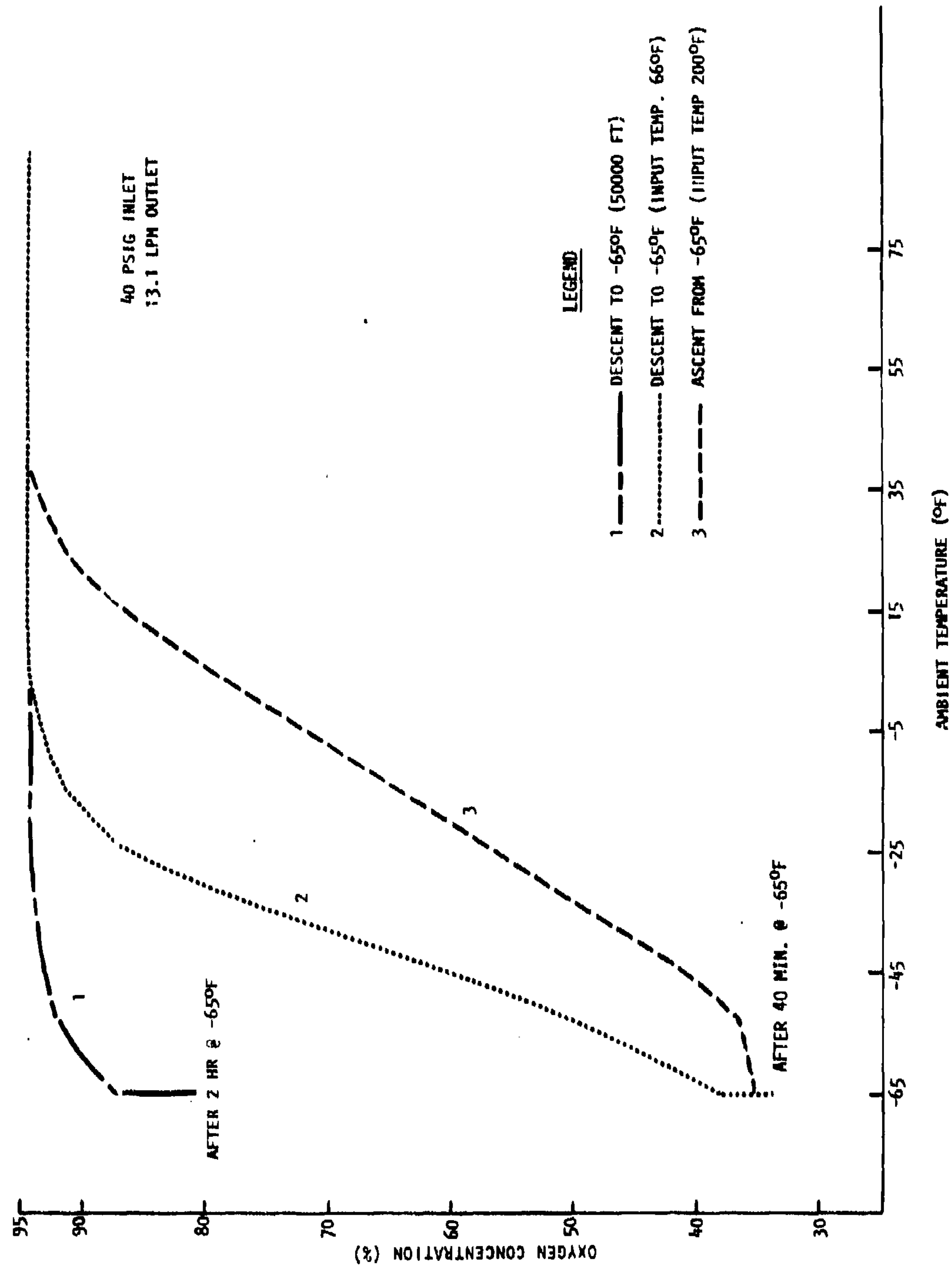

FIGURE 19 - Plot - Oxygen Concentration Versus Ambient Temperature

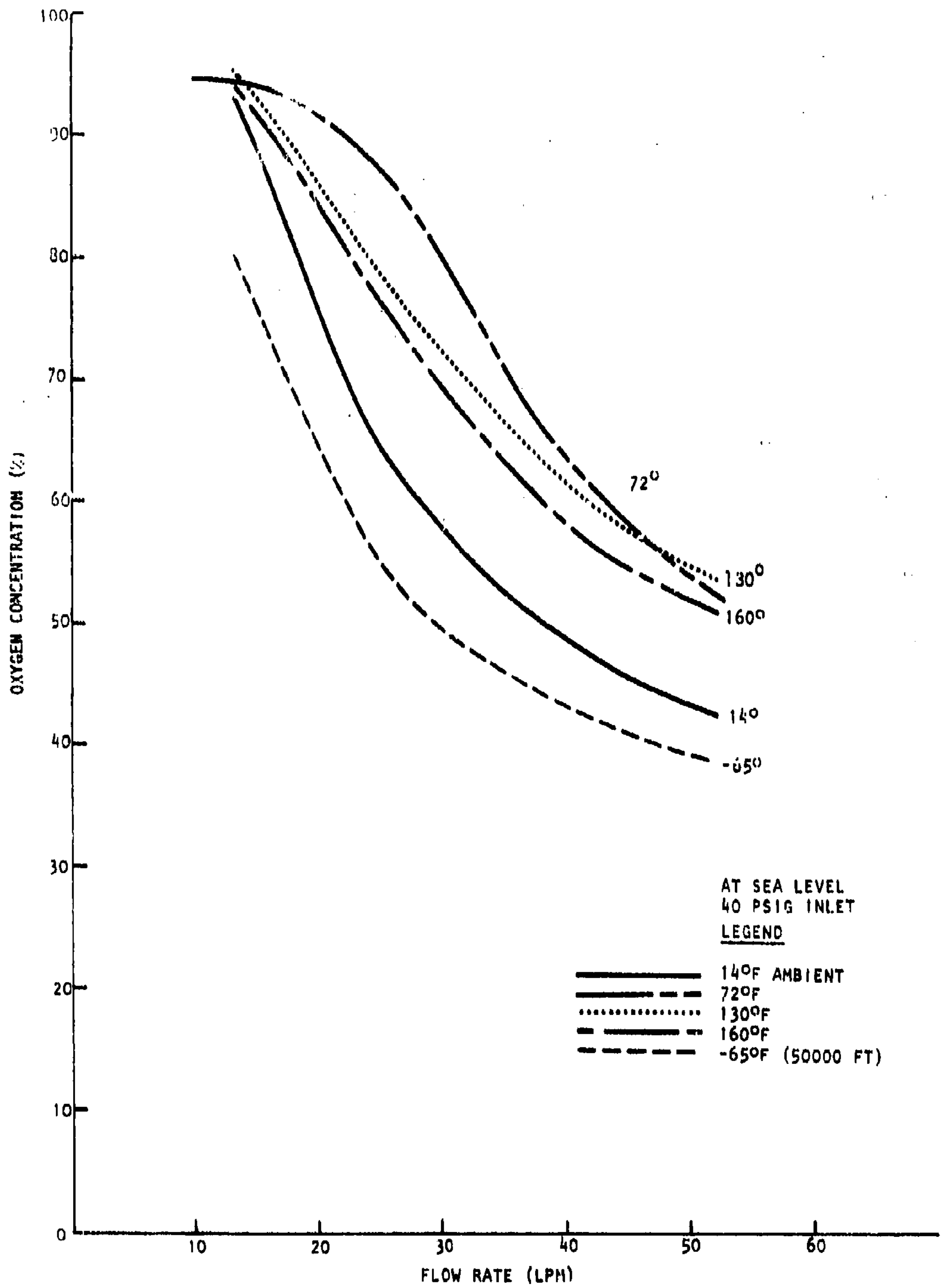

FIGURE 20 - Plot - Oxygen Concentration Versus Outlet Flowrate for Various Ambient Temps

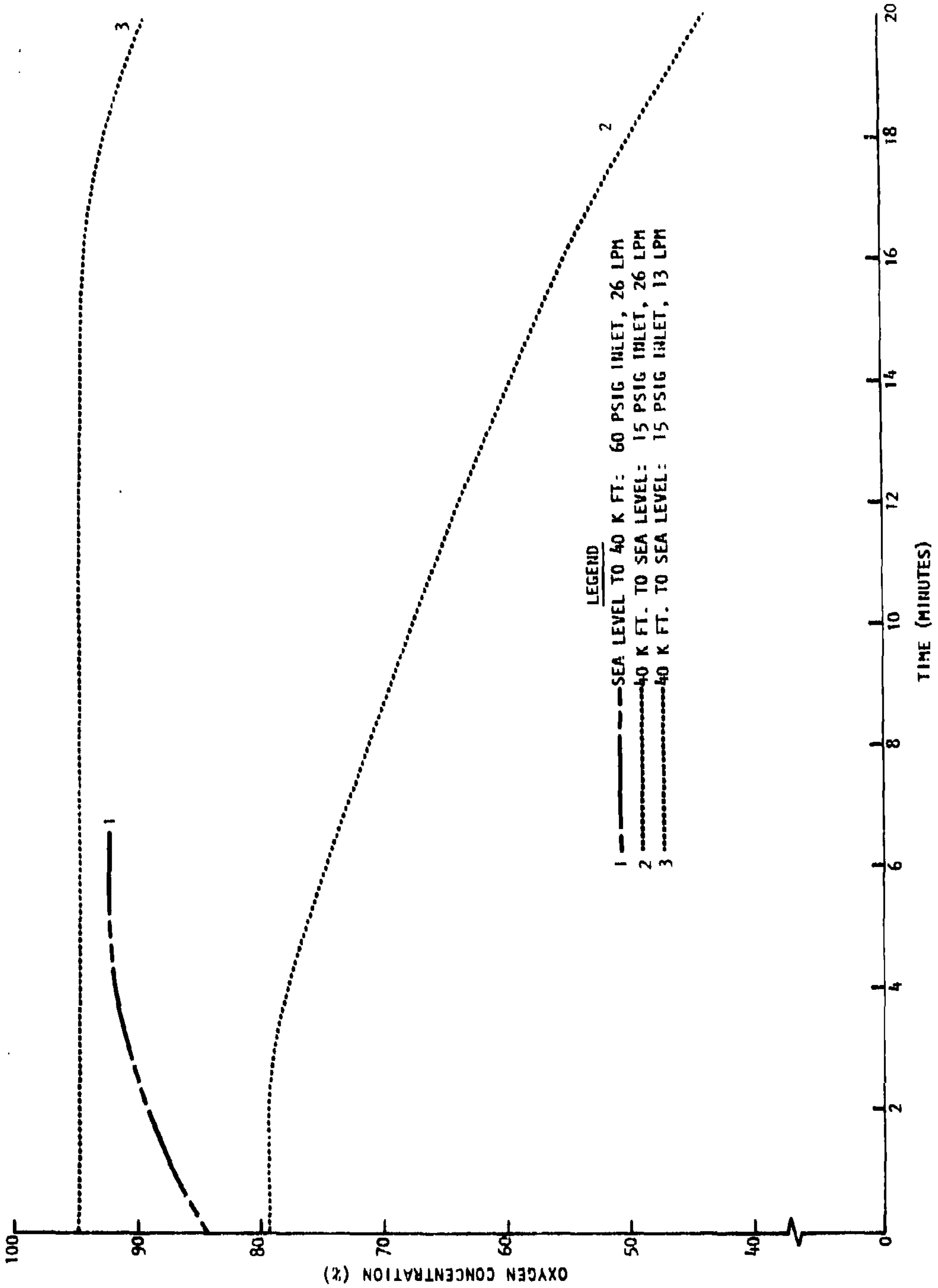

FIGURE 21 - Plot - Oxygen Concentration Versus Time (Ascent/Descent)

TABLE I

PRESSURE EFFECT OF INTERNAL REDUCER

INLET PRESSURE	REGULATED PRESSURE
40	40
50	43
60	44
80	47
100	50
120	52
140	56
180	58
195	62

TABLE II

OXYGEN REQUIREMENTS FOR EACH CREW MEMBER USING MASK WITH 100% OXYGEN

Cabin Altitude (Feet)	R (Liters Per Hour) Corrected to Sea Level & 70^{o} F Dry
Sea Level	787
5,000	637
10,000	504
15,000	405
20,000	326
25,000	248
30,000	190
35,000 and above	139

At this point, an additional test was added to the experimental protocol, the purpose of which was to observe unit performance when exposed to low ambient temperature and altitude. As chamber temperature was brought down to -65 degrees Fahrenheit, the chamber was also brought to the corresponding altitude (from ARDC Model Atmosphere), resulting in a two hour test at -65 degrees Fahrenheit, and 50,000 feet. Unit inlet and outlet conditions were as stated in the previous run. Results are presented in figure 19. Once again, performance degradation (drop in oxygen concentration) was noted with exposure to low ambinet temperature. The rate, however, is far less dramatic at 50,000 feet than at sea level. At the conclusion of this test, various outlet flowrates were drawn from the unit, and the corresponding oxygen concentrations shown in figure 20.

As poor performance at -65 degrees Fahrenheit was evident, it was decided to conduct a test at sea level, while admitting high temperature air (160 degrees Fahrengeit) to the unit to note any change in performance. The unit was allowed to stabilize at -65 degrees Fahrengeit for 40 minutes, not operating throughout this period. As power was supplied to the unit after stabilization, it drew 600 milliamps or three times its normal power consumption. After 30 minutes of operation, the unit then drew approximately 250 milliamps. The unit was supplied with 160 degree Fahrenheit air for 30 minutes, while oxygen concentration held at approximately 34 percent. Inlet air temperature was raised to 200 degrees Fahrenheit and supplied to the unit for one hour. After this period, oxygen concentration read 35.6 percent. Chamber ambient temperature was raised, and oxygen concentration increased as indicated by the curve of figure 19.

A two hour test was conducted at 14 degrees Fahrenheit ambient with an inlet air temperature of 60 +1 degrees Fahrenheit. Oxygen concentration had dropped from 94 percent at its beginning to 91.6 percent at its conclusion. Outlet flow was varied accordingly and the results presented in figure 20.

With chamber temperature and altitude raised to 95 degrees Fahrenheit and 50,000 feet, respectively, a two hour test was made to observe performance at these conditions. With 13.1 lpm drawn from the unit, a constant oxygen concentration of 95 percent was recorded throughout the test.

It was then intended to evaluate unit performance when subjected to high ambient temperature. Four hour and two hour tests were conducted at 130 and 160 degrees Fahrenheit, respectively, at sea level. Through each of these periods, inlet pressure was held at 40 PSIG and outlet flow at 13.1 lpm. Results were favorable at 130 degrees Fahrenheit, with an oxygen concentration of approximately 95 percent recorded throughout the four hour run. A slight drop in concentration was noted at 160 degrees Fahrenheit, with 93.7 percent oxygen recorded at the conclusion of the test. With flow variation for each condition, results were recorded and are presented in figure 20.

The following set of tests as listed in the experimental protocol deal with specific ascent/descent conditions. The intent of these tests was to note the effect on unit performance when subjected to varying rates of climb and descent only. Therefore, input pressures and outlet flowrates were held constant during each run. Test runs and their results are indicated in table

III. With high input pressure, (Run 1 through 9) varying rates of climb and descent had no appreciable effect on oxygen concentration. However, a problem arose when the unit was subjected to high altitude and low input pressure. Run 10 was initially intended to be conducted with an input pressure of 8 PSIG, to sinulate idle descent. Upon attaining an altitude of 40,000 feet (from fun 9), input pressure was lowered to 8 PSIG. 13 lpm could not be drawn from the unit at these conditions, with the outlet valve opened fully. Flow would fall to and hold at zero, rise to approximately 10 lpm, then fall back to zero. A constant flow of 13.1 lpm could be drawn when the inlet pressure was raised to 15 PSIG. A plot was made for those runs showing significant variation in oxygen concentration and is presented in figure 21.

Vibration tests were conducted on the MSOG in two parts, the first of which being a resonance search. A constant sinusoidal input of one G peak was used in each of the three attitudes, vertical, horizontal, and longitudinal through a frequency range of 5 to 500 Hz, with a total sweep time (up and down) of 15 minutes. With two sweeps conducted in each attitude, total vibration time was 90 minutes. The resulting resonant frequencies are listed in table IV (reference 7). The 50 to 70 Hz resonance in the vertical attitude resulted in a magnification factor of seven (i.e., a one G input produced a seven G response on the mounting plate.) The 50 to 80 Hz resonance in the horizontal (side to side) attitude gave a peak resonance of eight G on the sieve beds. The other resonant conditions as listed in the table, as well as some higher frequency vibrations, provided smaller magnification factors (less than five) with the one G peak input.

The second part involved testing with random vibration. Two 90 second tests were conducted, each with a bandwidth of 20 to 2000 Hz. Input accelerations were 3.0 and 3.8 G rms with spectral densities of 0.0045 and 0.0072 G^2/Hz, respectively. Throughout the random tests and while operating at a resonant frequency, no degradation in unit performance was observed, and no evidence of structural damage was found at the conclusion of the tests.

The MSOG was acceleration tested utilizing the centrifuge facilities of the Naval Air Development Center, with the unit subjected to the G levels as specified in the experimental protocol. Onset rates were 4.5 G/sec and 2 G/sec to 9 G and 4 G plateaus, respectively.

During each run, the unit was operating with an air inlet pressure of 25 PSIG and an enriched air outlet of 13.1 lpm. Rotating control valve speed (rpm) was monitored and recorded during each run. Leads from the unit tachometer were used to measure an output voltage, which corresponds to a particular rotational speed.

Output voltage, i.e., rotational speed, remained constant throughout each test (5.5 V, 3.5 rpm), and no visible structural damage to the unit was observed at the conclusion of the tests. A laboratory bench check verified normal operation, as oxygen concentrations observed showed no degradation in system performance.

TABLE III

RESULTS OF TEST INVOLVING VARYING RATES OF ASCENT AND DESCENT

RUN	ALTITUDE CHANGE (KFT)	TIME (MIN)	INLET PRESSURE (PSIG)	OUTLET FLOW (LPM)	OXYGEN CHANGE (%)
1	40 to 0	20.0	40	13.1	CONSTANT 95
2	0 to 20	1.5	40	13.1	CONSTANT 93.9
3	20 to 0	9.0	40	13.1	CONSTANT 94.9
4	0 to 40	6.6	40	13.1	CONSTANT 94.9
5	0 to 40	6.6	25	13.1	94.7 - 94.9
6	40 to 0	20.0	25	13.1	CONSTANT 94.9
7	0 to 20	1.5	25	13.1	94.6 - 94.9
8	20 to 0	9.0	25	13.1	94.9 - 94.7
9	0 to 40	6.6	60	13.1	CONSTANT 94.7
10	40 to 0	20.0	15	13.1	94.7 - 89.4
11	0 to 20	1.5	60	13.1	CONSTANT 94.7
12	20 to 0	9.0	15	13.1	94.9 - 93.8
13	0 to 40	6.6	60	26.2	84.5 - 92.1
14	40 to 0	20.0	15	26.2	79.4 - 43.2

TABLE IV

RESONANT FREQUENCIES IN EACH ATTITUDE

ATTITUDE	FREQUENCY (Hz)
Vertical	50-70 90-115
Longitudinal (Fore to Aft)	50-70 90-115
Horizontal (Side to Side)	50-80

CONCLUSIONS AND RECOMMENDATIONS

Test data from this evaluation program have verified that the Molecular Sieve Oxygen Generator will provide adequate quantities of breathing gas and sufficient oxygen concentrations for a two-man breathing schedule to an altitude of 32,000 feet without pressure breathing. Studies completed by the Air Force School of Aerospace Medicine (1, 6) have indicated that the argon concentrations in the molecular sieve product gas will not present any risk.

It can be concluded from the results that there are three parameters which have the most critical impact on the performance of the unit. They are: inlet pressure, ambient temperature, and outlet flowrate. These parameters have been addressed in subsequent development efforts by ensuring aircraft interface provides adequate quantities of process air, including thermal control systems integral with the unit, and sizing the unit to meet breathing flowrate requirements. The structural integrity of the unit has been demonstrated through vibration and acceleration testing.

It is recommended that flight testing on-board the EA-6B commence with the three parameters mentioned previously being closely monitored. Also, the results of flight testing with regards to breathing rates must be examined closely, and the data be considered in future development.

REFERENCES

(1) Ikels, K. G., and J. D. Adams - Molecular Sieve Oxygen Generating System: The Argon Question, Unpublished Report USAF School of Aerospace Medicine, Brooks AFB, TX, Jan 1978.

(2) Military Specification, MIL-D-19326E - Design and Installation of Liquid Oxygen Systems in Aircraft, General Specification For, Mar 1970.

(3) Military Specification, MIL-R-25410F, Regulators, Oxygen, Diluter-Demand Automatic-Pressure Breathing, 15 Jan 1968.

(4) Military Standard, MIL-STD-810C - Environmental Test Methods, 10 Mar 1975.

(5) NATOPS Flight Manual, Navy Model EA-6B Aircraft, NAVAIR 01-85ADC-1, 1 Jun 1977.

(6) Stork, R. L., C. F. Theis, K. G. Ikels, and R. L. Miller - Human Compatability Testing of a Two-Man Molecular Sieve Oxygen Generator, Unpublished Report, USAF School of Aerospace Medicine, Brooks AFB, TX Jan 1978.

(7) Vibration Testing of the Molecular Sieve On-Board Oxygen Generator, Bendix Corporation letter of 27 Jan 1978.

APPENDIX A

EXPERIMENTAL PROTOCOL

EXPERIMENTAL PROTOCOL

1. OBJECTIVES

The object of this evaluation program is to verify that the design criteria have been met and establish that the unit will not be hazardous to aircraft and/ or personnel during flight testing. The program is required to establish the performance of the unit in the environment anticipated during developmental flight test.

2. EXPERIMENTAL DESIGN

The experimental design for the evaluation of the OBOG unit is as follows:

a. The resources, or aircraft interfaces, required by the molecular sieve are:

(1) Bleed air temperature - 65 to 160 degrees Fahrenheit; pressure 25 to 60 PSIG.

(2) Electrical power - 28V DC (o.2 amps normal operation).

b. The bleed air will be varied through the specified range and the effect upon performance of the unit noted.

c. The unit will also be subjected to altitude conditions as well as altitude changes (ascent and descent).

d. Oxygen output, both quantity and quality, will be closely monitored during each run.

3. TEST DESCRIPTION

The following is a description of the testing that will be performed:

a. Performance Envelope - The first series of runs will be to establish the performance of the unit and will be divided as follows:

(1) Reference Runs - A reference run will be performed at standard conditions to establish a baseline. This will be repeated during the series to determine if the unit has been permanently affected by any of the test conditions.

(2) Process Air Pressure/Altitude/Outlet Flowrate - A 100 point matrix will be utilized to vary input process air pressure, ambient exhaust pressure, and enriched air outlet flowrate with tho values as shown and to note the effect of each on unit performance.

INLET PRESSURE (PSIG)	OUTLET FLOW (LPM)	ALTITUDE (KFT)
8, 15, 25, 40, 60,	13.1, 26.2. 39.3, 52.4, 78.6	0, 20, 40, 50

(3) Process Air Temperature - Variation as shown below will be imposed on the process air temperature and observations made of the effect on the performance of the unit.

INLET PRESSURE (PSIG)	OUTLET FLOW (LPM)	INLET AIR TEMPERATURE (°F)
40	13.1	14,30,70,100,120,160

(4) Ambient Temperature - Ambient (chamber) temperature will be varied through the specified range for the outlet flows as shown and its effect on unit performance noted.

INLET PRESSURE (PSIG)	OUTLET FLOW (LPM)	AMBIENT TEMPERATURE (°F)
40	13.1,26.2,39.3,52.4	-65,14,95,130,160

(5) Altitude Changes - The runs shown below will be conducted to simulate both climb and descent to observe the effect of varying exhaust pressure as a function of time.

INLET PRESSURE (PSIG)	OUTLET FLOW (LPM)	CLIMB;RATE (KFT;MIN)	DESCENT;RATE (KFT;MIN)
15	13.1	-	40-0; [illegible]0.0
		-	20-0; 9.0
	26.3	-	40-0;20.0
25	13.1	0-40; 6.6	40-0;20.0
		0-20; 1.5	20-0; 9.0
40	13.1	0-40; 6.6	40-0;20.0
		0-20; 1.5	20-0; 9.0
60	13.1	0-40; 6.6	-
		0-40; 1.5	-
	26.2	0-40; 6.6	-

b. Vibration - The unit will be subjected to vibration testing through a resonance search procedure. The unit will be excited with sinusoidal input through the overall frequency spectrum to determine what resonant frequencies do exist and observe the effect on unit performance when operating at resonance. If proven feasible, a low level random vibration test will also be conducted.

c. Acceleration - The unit will be subjected to acceleration testing to insure it is structurally sound and capable of withstanding G forces anticipated during flight testing. The following G levels will be attained for a duration (plateau time of 30 seconds each:

± 9 Gx (Fore/Aft Attitude)
± 4 Gy (Side/Side Attitude)
± 9 Gz (Down)
± 1 Gx (Up)

4. Responsible project personnel are as follows:

Program Manager	- Mr. E. Boscola
Project Engineer	- Mr. M. Lamb
Project Engineers (Testing)	- Mr. R. Routzahn
	- Mr. D. McCauley
Laboratory Technicians	- Mr. S. Morgera
	- TD2 S. Eakins

APPENDIX B

RUN MATRIX

RUN MATRIX

INLET PRESSURE (PSIG)	ALTITUDE (KFT)	OUTLET FLOW (LPM)	OXYGEN (%)
8	0	13.1	43.5
		26.2	32.0
		39.3	28.2
		44.0 (MAX)	28.0
	20	13.1	94.2
		20.0 (MAX)	67.0
	40	10.0 (MAX)	94.4
15	0	13.1	74.2
		26.2	46.0
		39.3	38.0
		52.4	34.0
		70.0 (MAX)	29.8
	20	13.1	94.8
		26.2	71.0
		39.3	55.0
		49.0 (MAX)	48.7
	40	13.1	94.8
		26.2	81.0
		39.3	55.0
		45.0 (MAX)	59.0
	50	13.1	94.8
		26.2	75.0
		39.3	64.0
		43.5 (MAX)	60.2
25	0	13.1	94.0
		26.2	64.0
		39.3	48.0
		52.4	43.0
		78.6	35.5
	20	13.1	94.8
		26.2	84.3
		39.3	65.4
		52.4	55.6
	40	13.1	95.0
		26.2	90.4
		39.3	71.5
		52.4	60.8
	50	13.1	94.8
		26.2	89.4
		39.3	70.3
		52.4	59.4
40	0	13.1	94.5
		26.2	86.0
		39.3	64.0
		52.4	52.0
		78.6	42.0

INLET PRESSURE (PSIG)	ALTITUDE (KFT)	OUTLET FLOW (LPM)	OXYGEN (%)
40	20	13.1	94.8
		26.2	92.8
		39.3	72.4
		52.4	61.4
	40	13.1	94.8
		26.2	92.7
		39.3	77.1
		52.4	65.4
	50	13.1	94.6
		26.2	91.8
		39.3	73.4
		52.4	62.4
60	0	13.1	94.2
		26.2	86.7
		39.3	68.0
		52.4	56.0
		78.6	44.5
	20	13.1	94.7
		26.2	93.1
		39.3	78.2
		52.4	64.3
	40	13.1	94.7
		26.2	93.5
		39.3	79.1
		52.4	66.6
	50	13.1	94.9
		26.2	92.6
		39.3	77.5
		52.4	64.4

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